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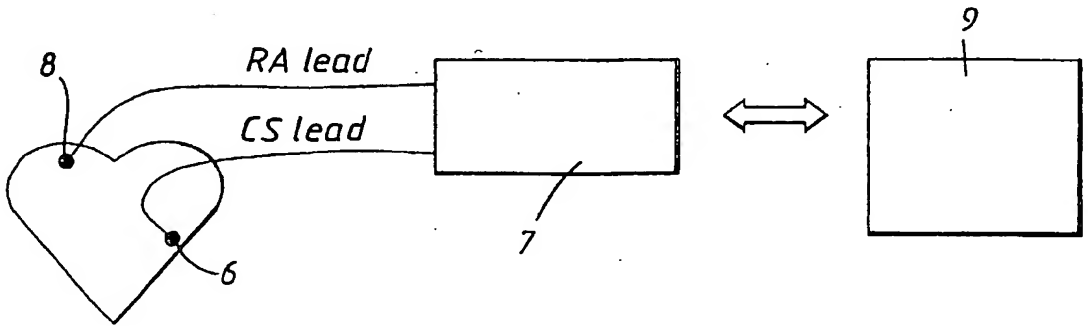
(54) Title: A CONGESTIVE HEART FAILURE MONITOR



(57) Abstract: A congestive heartvfailure monitor comprises an impedance measuring unit to measure the impedance between at least two electrodes intended to be implanted in a patient such that a change in the left atrium volume results in a change of the measured impedance. Analysing means are provided for analysing the measured impedance for detecting an incipient congestive heart failure.

WO 2004/008959 A1

A CONGESTIVE HEART FAILURE MONITOR

Technical field

The present invention relates to a congestive heart failure monitor.

Background

Electrical stimulation therapy of congestive heart failure is previously known. Thus in US 5 584 868 a dual-chamber pacemaker designed for treating congestive heart failure (CHF) by changing the AV interval is described and in US 6 223 079 B1 a four chamber pacing system for improving cardiac output of CHF patients by controlling pacing to maintain the ventricular mechanical synchronization is disclosed. For providing suitable timing in the latter system impedance sensing in the left heart is used.

Incipient CHF is often present without the patient knowing it. An indicator for incipient CHF would therefore be of great value since treatment by addition of drugs or electrical stimulation therapy could then be introduced at an early stage of CHF to slow down the progression of CHF. This would prolong the survival of the patient. Such an indicator could also be used to alert the patient or the physician about new conditions so appropriate measures can be taken. The first sign of a CHF can be seen in the left atrium, for instance in volume changes thereof.

The purpose of the present invention is to utilize this knowledge to provide a congestive heart failure monitor for detecting CHF at an early stage.

Disclosure of the invention

This purpose is obtained by a congestive heart failure monitor acoording to claim 1.

The first sign of a CHF can be observed in the left atrium of the heart by monitoring its mechanical behaviour, like volume changes, as mentioned above. If the pumping ability of the left ventricle is reduced the volume of the left atrium will increase due to the excessive filling of blood. The filing pattern of the left atrium can be disturbed due to mitral regurgitation caused by either diastolic or systolic dysfunction. The diastolic dysfunction could be a result of prolonged PR interval, i.e. the P-wave to QRS interval or too long an AV interval, resulting in reversed flow back to the left atrium during diastole as the mitral valve does not close im-

mediately after the atrial contraction. The systolic dysfunction could be a result of infarctic areas in the left ventricle which disturbs the left ventricle contraction propagation so that the mitral valve cannot close properly, (the papillar muscle get asynchronous), bringing reversed flow back to the left atrium during systole. The systolic dysfunction in the left ventricle could also be a result of bad timing of the right and left ventricle stimulations (e.g. septum, innervated at RVOT stimulation, is involved in the left ventricle contraction) causing mitral regurgitation and disturbed filling pattern of the left atrium. All these conditions results in a disturbed filling pattern of the left atrium and is one of the first signs of CHF.

A first sign of CHF can thus be observed in the left atrium and since the conductivity of blood is different from that of tissue the monitor according to the invention comprises an impedance measuring unit adapted to measure impedance between at least two electrodes intended to be implanted in the patient such that a change in the left atrium volume results in a change in the measured impedance. In this way not only incipient CHF can be detected but the monitor according to the invention can also be used as a diagnostic tool for studying the progression or regression of CHF for enabling proper treatment of the patient.

According to advantageous embodiments of the monitor according to the invention the analyzing means comprise an averaging means provided to form a mean value of the measured impedance during a plurality of cardiac cycles and the analyzing means are adapted to analyze the mean value to detect CHF or said analyzing means comprise a quotient determining means provided to determine the quotient between the impedance minimum and maximum values during a cardiac cycle, and the analyzing means are adapted to analyze the quotient to detect CHF. Preferably the analyzing means are adapted to analyze both the impedance mean value and the quotient to detect CHF. Firstly, even though the impedance changes continuously during the heartbeat, the mean value will decrease when the left atrium volume increases. Secondly, the quotient between the impedance minimum and maximum values will be larger, with increasing blood filling of the left atrium. Accordingly with the present invention an efficient CHF monitor is provided based on the analysis of these two quantities.

According to other advantageous embodiments of the monitor according to the invention the electrodes are designed for implantation in the right and left atria, respectively, or for implantation in the right atrium and left ventricle. In case

of an implantable monitor, one of the electrodes can be designed for implantation in the left atrium and the other electrode be formed of the outer capsule of the monitor, e.g. the pacemaker capsule when the monitor is included in a pacemaker.

Also other combinations of the above mentioned electrodes can be used for the impedance determination.

The electrodes intended for implantation in the left atrium and the left ventricle are preferably designed for implantation in a coronary vein. For all these alternatives signals corresponding to the blood filling of the left atrium are obtained from the electrodes.

According to still other advantageous embodiments of the monitor according to the invention the impedance measuring unit comprises a measuring circuit in the form of synchronous demodulator for obtaining both the real and imaginary parts of the impedance, and the impedance measuring unit is preferably adapted to determine the impedance phase angel for detecting and the analysing means is adapted to analyse the phase angle for detecting an incipient CHF. Since blood is resistive a high degree of blood filling results in a small phase angle. On the contrary, if more heart tissue is present, like in case of a healthy heart, the phase angle will get a larger negative value.

Brief description of the drawings

To explain the invention in greater detail embodiments of the monitor according to the invention chosen as examples will be described below with reference to the enclosed drawings, on which figure 1 illustrates principally the impedance measurements performed in one embodiment of the monitor according to the invention, figure 2 is a simplified illustration of an embodiment of the monitor according to the invention, figure 3-5 illustrate alternative ways of performing impedance unit of the monitor according to the invention, and figure 7 is a flow chart illustrating the signal processing in an embodiment of the monitor according to the invention.

Detailed description of embodiments

Figure 1 illustrates principally measurement of the impedance Z between the right atrial lead 2 and the coronary sinus lead 4. As the left atrium is dilated due to CHF the impedance Z will decrease. Also the variation of the impedance

between maximum and minimum values will then decrease due to increased wall tension.

To secure a safe fixation of the left atrial electrode 6 in the coronary sinus CS or the great cardiac vein it is beneficial to use a screw-in electrode, cf. figure 2. The optimal right atrial RA electrode 2 position is lightly to be in the inter-atrial septum near the coronary sinus ostium, see the electrode tip 10 in figure 3. With the electrodes 6, 8; 10,11 positioned as shown in figures 2 and 3 the volume of the left atrium is positioned between the electrodes. This enables variations of impedance variations across the left atrium and a high sensitivity to left atrium volume changes.

Also other bipolar electrode measurements set-ups as well as tripolar electrode settings are possible in the monitor according to the invention.

The embodiment of the monitor according to the invention shown in figure 2 comprises monitor electronics 7 for analysis of the measured impedance for detection of an incipient CHF. An implantation monitor is preferably also provided with telemetry means, not shown in figure 2, for communication with an external programmer and data acquisition device 9.

Figures 3-5 illustrate quadropolar electrode configurations suitable for use in the monitor according to the invention. In figure 3 the coronary sinus CS lead 12 is positioned on the left atrium and in the figures 4 and 5 the CS lead 14 and 16 respectively is placed on the left ventricle.

The method of bio-impedance measurement is not critical in the monitor according to the invention. Figures 3-5 illustrate a technique wherein an electric current i(t) is supplied between two electrodes and the resulting evoked voltage response v(t) is detected. In the embodiments shown in figures 3 and 5 the evoked voltage response i(t) is supplied. Figure 4 shows an embodiment in which the current i(t) is supplied between a right atrial electrode 17 and a stimulator can 19, whereas the evoked voltage response is measured between the right atrial electrode 17 and a left ventricular electrode 18 positioned in the coronary sinus.

Figure 6 shows an alternative embodiment of the impedance measuring unit of the monitor according to the invention in the form of a synchronous demodulator. Generally the electric current i(t) is applied to two electrodes 20, 22 and the resulting evoked response is measured between two measurement electrodes 24 and 26. The measured voltage signal is amplified in an amplifier 28. The

measured voltage signal is synchronized with the current i(t) with the aid of a reference signal picked up from the current source 21 and supplied to synchronizing means in the form of multiplier 30. A low-pass filter 32 is provided to filter the output signal from the multiplier 30. The resulting impedance Z_1 is the given by the expression

$$Z_1 = u_1 / i$$

where u_1 denotes the filtered resulting synchronized output voltage signal.

With the impedance measuring circuit shown in figure 6 both the real and the imaginary parts of the impedance are measured and consequently the impedance phase angle is obtained too.

As discussed above, at left ventricular dysfunction the left atrium will dilate according to the progress of the disease, because the left ventricle is not able to eject blood into the body and blood will consequently stagnate in the left atrium and pulmonary veins. Left atrium blood pressure will increase as well as left atrium wall tension. The blood volume in the left atrium will also increase while the variation between maximum and minimum volume values will decrease. These phenomena can be determined from the measured impedance.

Figure 7 is a flow chart illustrating an example of an embodiment of the monitor according to the invention analysing the impedance minimum-maximum quotient and the overall impedance mean value for detecting an early CHF. The impedance raw signal obtained as explained above is pre-filtered, at 34 in the figure. The filtering at 34 is performed to remove artefacts of noise, breathings etc. Mean value of the impedance signal during the last heart cycle is calculated in averaging means, at 36, and long time mean value calculation is performed by means of a low pass filter, at 38. The expression "long time" could mean a time of the order of typically 10 minutes in this connection.

At 40 in figure 7 the quotient between the impedance minimum and maximum values is determined. The obtained long term mean value and the quotient between minimum and maximum values are compared with predetermined reference or normal threshold values in comparison means, at 42 in the figure. The results of these comparisons are used, at 44, to classify the patient's condition according to predetermined built-in rules.

The processing described above with reference to figure 7 can advantageously be used together with an activity sensor and a posture sensor. The im-

pedance properties can then be calculated during the same conditions for the patient, for instance with the patient in a resting supine position. The processing chain of figure 7 can also preferably contain a memory for saving the time history of calculated parameters for further evaluation in external devices, cf. figure 2.

CLAIMS

1. A congestive heart failure monitor comprising an impedance measuring unit (7; 30, 32) adapted to measure the impedance Z between at least two electrodes (2, 4; 6, 8; 10, 12; 17, 18; 20, 22, 24, 26) intended to be implanted in a patient such that a change in the left atrium volume results in a change of the measured impedance, and analysing means (7, 9; 36, 38, 40, 42, 44) for analysing said measured impedance for detecting an incipient congestive heart failure (CHF).

2. The monitor according to claim 1, **characterized** in that said analysing means comprise an averaging means (36, 38) provided to form a mean value of said measured impedance during a plurality of cardiac cycles, and in that said analysing mans are adapted to analyse said mean value to detect CHF.

3. The monitor according to claims 1 or 2, **characterized** in that said analysing means comprise a quotient determining means (40) provided to determine the quotient between the impedance minimum and maximum values during a cardiac cycle, and in that said analysing means are adapted to analyse said quotient to detect CHF.

4. The monitor according to claim 2, **characterized** in that a first comparison means is provided to compare said impedance mean value with a predetermined impedance threshold value, said analysing means being adapted to detect CHF from the result of said comparison

5. The monitor according to claims 3 or 4, **characterized** in that said analysing means comprise quotient averaging means provided to form a mean value of said quotient during a plurality of cardiac cycles, and in that said analysing means are adapted to analyse said mean value to detect CHF.

6. The monitor according to claims 3 or 5, **characterized** in that a second comparison means is provided to compare said quotient or said mean value of the

quotient with a predetermined quotient threshold value, said analysing means being adapted to detect CHF from the result of said comparison.

7. The monitor according to claim 4, **characterized** in that said averaging means is adapted to form a floating mean value of the measured impedance during a predetermined number of preceding cardiac cycles for use as said impedance threshold value.

8. The monitor according to claim 6, **characterized** in that said quotient averaging means are adapted to form a floating mean value of said quotient determined during a predetermined number of preceding cardiac cycles for use as said quotient threshold value.

9. The monitor according to any of the claims 2 – 8, **characterized** in that said analysing means are adapted to analyse said impedance mean value and said quotient to detect CHF.

10. The monitor according to claims 4 and 6, **characterized** in that said first and second comparison means are one and the same comparison means (42).

11. The monitor according to any of the preceding claims, **characterized** in that said electrodes (6, 8; 10, 12) are designed for implantation in the right and left atria, respectively.

12. The monitor according to any of the claims 1-10, **characterized** in that said electrodes (2, 4; 17, 18) are designed for implantation in the right atrium and left ventricle.

13. The monitor according to any of the claims 1-10, said monitor being implantable, **characterized** in that one of said electrodes (18) is designed for implantation in the left atrium and the other electrode is formed of an outer capsule of the monitor.

14. The monitor according to any of the claims 11 - 13, **characterized** in that said electrodes (12; 18; 16) for implantation in the left atrium and the left ventricle are designed for implantation in a coronary vein.

15. The monitor according to claim 1, **characterized** in that said impedance measuring unit comprises a measuring circuit in the form of a synchronous demodulator for obtaining both the real and imaginary parts of the impedance (fig. 6).

16. The monitor according to claim 15, **characterized** in that said impedance measuring unit is adapted to determine the impedance phase angle and in that said analysing means are adapted to analyse the phase angle for detecting an incipient CHF.

17. A multisite heart stimulator, **characterized** by a monitor according to any one of the preceding claims.

18. The stimulator according to claim 17, **characterized** by a control unit provided to control the stimulation of the patient's heart in response to an output signal received from said monitor and representing the results of the analysis of the measured impedance, in order to optimize hemodynamics.

10/524196

Fig. 1

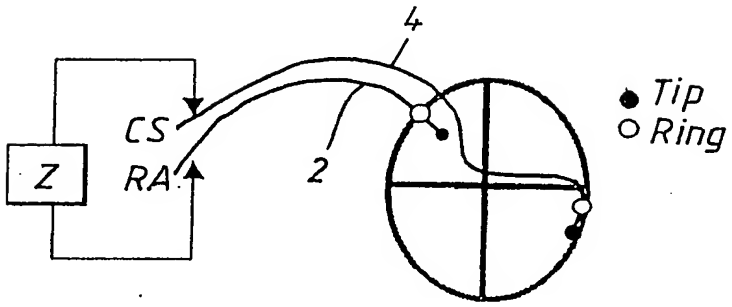


Fig. 2

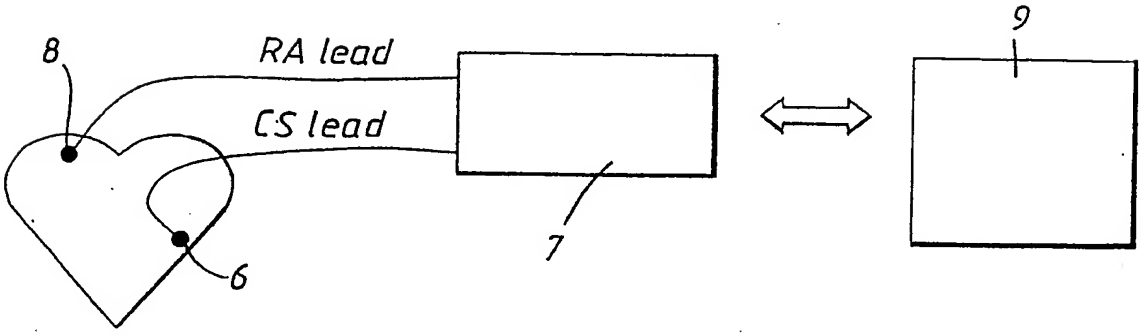


Fig. 3

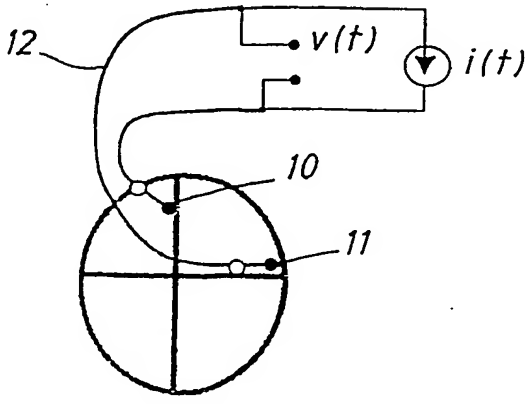


Fig-4

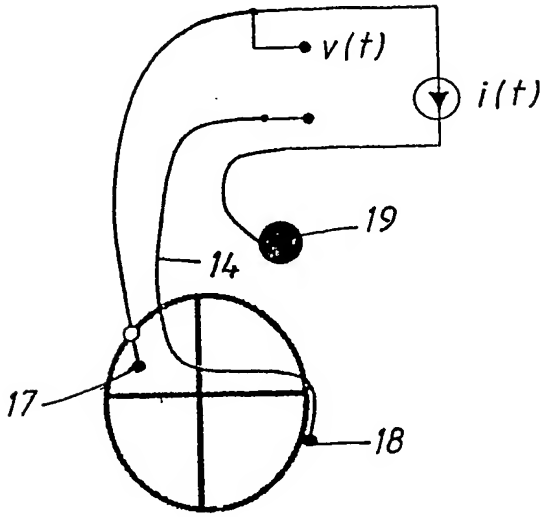


Fig-5

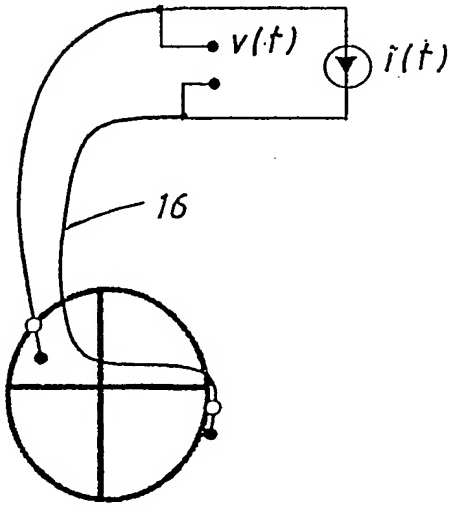


Fig. 6

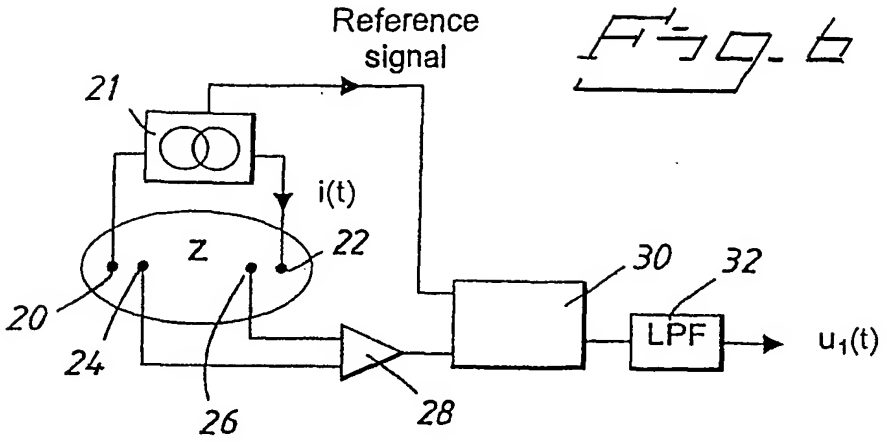
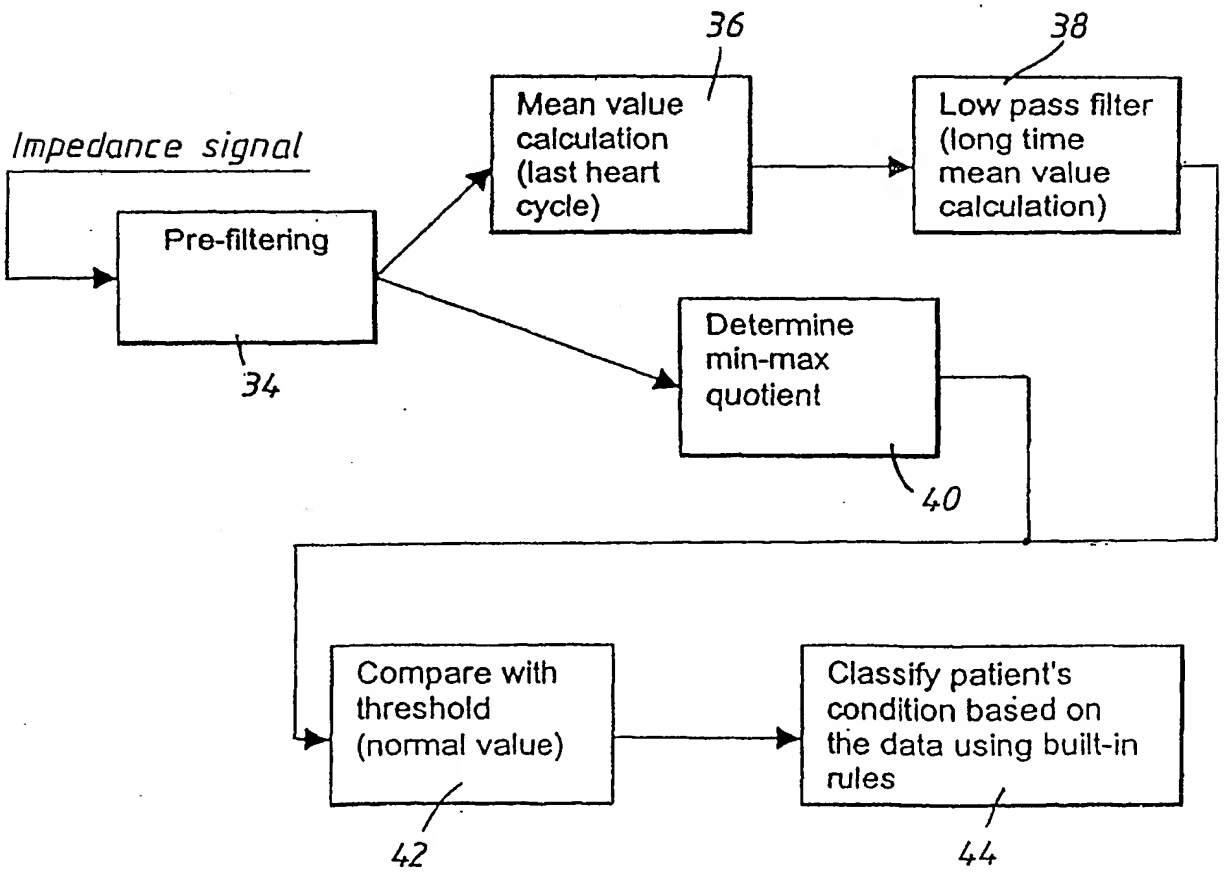

Reference signal
21
i(t)
Z
22
20
24
26
28
30
32
LPF
$u_1(t)$

Fig. 7


Impedance signal
Pre-filtering
34
Mean value calculation (last heart cycle)
36
Low pass filter (long time mean value calculation)
38
Determine min-max quotient
40
Compare with threshold (normal value)
42
Classify patient's condition based on the data using built-in rules
44

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 03/01081

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: A61B 5/053, A61N 1/368
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: A61B, A61N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, PAJ, INSPEC, MEDLINE, BIOSIS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6223079 B1 (BAKELS, A. ET AL), 24 April 2001 (24.04.01), column 4, line 1 - line 10; column 6, line 55 - line 66; column 10, line 11 - line 25	1-14,17-18
A	--	15-16
A	EP 0985429 A2 (VITATRON MEDICAL B.V.), 15 March 2000 (15.03.00), see paragraph 27 - 31	2-10
	--	
A	US 6278894 B1 (SALO, R.W. ET AL), 21 August 2001 (21.08.01), abstract	1-18
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 Sept 2003	26 -09- 2003
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Sofie Carlsson/mj Telephone No. +46 8 782 25 00

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 03/01081

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4674518 A (SALO. R.W.), 23 June 1987 (23.06.87), abstract -- --------	1-18

INTERNATIONAL SEARCH REPORT

Information on patent family members

26/07/03

International application No.
PCT/SE 03/01081

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